THE PHYSIOLOGICAL COSTS OF ARM MOTIONS
WHILE SITTING AND STANDING

by

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INTRODUCTION

The industrial engineer in his attempts to improve working standards and increase production has resorted primarily to using time as the basis of all his measurements of human activity. Any differences in physiological requirements have either been ignored or dealt with in a haphazard way by applying crude and inaccurate allowances. Wage incentives, plant design, and man-machine systems designs and analysis are functions of the Industrial Engineer which require a fundamental understanding of human energy expenditures.

Hicks (1955) explained the reason we get tired. He quoted Dr. Brouha, "You have a 'bank account' of energy which you build up by deposits to your credit whenever you rest. As you work, you make withdrawals from your account. At that precise point, exhaustion sets in, and you may never be able to build up your account again."

From the physiological point of view, the human body may be thought of as a machine which consumes fuel and gives out useful energy (Barnes, 1964). Physiological cost refers to the cost to the body caused by doing physical work. McCormick (1964) states that physiological fatigue is the reduction in the ability of the muscle to contract that is brought about by physiological changes within the muscle that occurs through work. It develops when a muscle is caused to contract at such a rate of work, and over such a period of time, that there is an accumulation of

waste products. As waste products start to accumulate, the muscle becomes less responsive to normal stimulation.

"Sit to work whenever possible" has long been a recommendation of those who would help workers ease the load of work. Usually this advise is given as a general recommendation with little experimental evidence; this thesis investigated the physiological cost of doing a task while standing and while seated.

LITERATURE REVIEW

The literature review has been divided into two parts. Physiological cost of doing the task was measured by a force platform, hence some investigations, which used output from a force platform as the index of physiological cost, are reported in the first part. The second part is concerned with arm motions in the horizontal plane.

Physiological Cost Indices

Numerous experiments have been performed to study the physiological effects of muscular work of varying degree of intensity. Oxygen consumption, heart rate and the force platform are the most commonly used methods.

One of the earliest approach to physiological measurements is known as the carbon dioxide method. In this method the oxygen consumed during the performance of the task is recorded; from this the calories expended can be estimated. Ingenohl (1959) cited the studies by Atzler and Crowden who measured physiological cost by measuring the amount of oxygen converted into CO_2. One problem in this method is the time lag before the body actually begins to absorb O_2 and expell the CO_2.

Though heart rate is a sensitive indicator of physiological cost, it also considers the operator's "machine efficiency". Nichols and Amrine (1959) stated that the heart rate is affected by environmental temperature, relative humidity, and the amount of clothing worn. The heart rate is known to vary from day to

day even during the course of the day. It is also affected by psychological factors.

Nichols and Amrine investigated some principles of motion economy using heart rate as their criterion. They assumed that a faster heart rate was associated with more effort or energy exerted. Fahnestock et. el. (1963) point out, however, that there is not a linear relationship between the energy spent and the heart rate (Konz & Day, 1966).

Oxygen consumption and heart rate can be used to measure work only when the physical activity is of considerable magnitude and duration. Light hand or body movements, for example, cannot be measured using these techniques. The force platform seems to be useful in measuring the physical effort involved in performing light work or activities of short duration. The platform has the key characteristic of being independent of the "machine efficiency" of the particular subject.

Lucien Lauru (1957) developed the first force platform and he called it an "effort detector". Greene (1957) improved Lauru's platform. Greene's platform was triangular in shape supported by three cantilever beams—one at each end of the platform. For each of the three axes, vertical, lateral, and frontal, the amount of deflection was translated to a voltage by a Linear Variable Differential Transformer (LVDT) to determine the three orthogonal components of any given force. The force trace originates from an established zero mark and deviates up or down. The data obtained from the instrument correlates

significantly with the physical definition of work i.e., force acting through a distance.

A more recent force platform design was by Barany and Whetsel (1962) (Hearn, 1966). They installed another set of three cantilever beams which apply forces vertically downward. Hearn's force platform was similar to Barany and Whetsel's with modifications and one unique characteristic--torque measurement. Torque measurement was accomplished by the incorporation of two additional LVDT's for each axis of rotation. The output voltage of all 9 LVDT's may be recorded on three two-channel recorders. This results in a record of bodily forces and torques exerted in performing a task.

Several investigations were carried out on the force platform since 1957.

Jacobson (1960) studied a dynamic evaluation of the force platform. The force platform had sufficient sensitivity to measure 1/2 pound force in the frontal axis and 1 pound force in the lateral axis. He concluded that this minimum force sensing capabilities was unaffected by frequencies of force application from 50-200 cpm or by variation in subject weight from 100 to 200 pounds.

Barany (1963) investigated the nature of individual differences in bodily forces exerted by a group of subjects who performed a simple motor task. He concluded that:

1. A very large portion of the variation in the amount of force exerted per cycle can be attributed to individual differences.

2. There was no relationship between average force index and rate of output for the total number of subjects taken collectively.
3. There was no relationship between any one of the anthropometric measurements(arm reach, chest circumference, height and weight) and the force exerted per unit of production.

Barta (1962) investigated the existence of a relationship between the external force (measured by the force platform) exerted by a worker and time as the criterion for work measurement. He found that the three components of external force, measured by the force platform, increased at a much greater rate than the increase in time as the weight handled increased from 0.35 to 12.92 pounds.

Horizontal Arm Motions

Corrigan and Brogden (1948) found that the precision of linear, constant-velocity movements of the right arm is a function of the angle from the body at which movement is made. The trigonometric relationship is:

$$Y = a - 2b \cos 2x + c \sin 2x$$

where, Y = precision of the right arm movements in terms of group mean frequency of stylus contact.

x = angle from the body at which the movement is made.

a, b and c are constants.

They performed three experiments with different sets of angles and incremented the angles by 30 degrees. Subjects moved the metal tipped stylus on a 0.4 cm. wide glass track positioned at different angles and the number of stylus contacts made on the side of the track was recorded at each angle by means of an electronic counter.

Corrigan and Brogden (1949) tested the validity of the trigonometric relationship. In general, the experimental task was the same as the previous one, except that the direction of the track was incremented at intervals of 15 degrees around the circle instead of having three different groups of angles. The number of contacts of the stylus with the track sides was recorded for each of the angles. Maximum errors were observed at 135 degrees and 315 degrees, and minimum number of errors was observed at 45 degrees and 225 degrees. They concluded that the trigonometric relationship between the precision of pursuit movements and the angle holds good.

Briggs (1955) studied the effect of distance, angle and the target size on the hand movements in the horizontal plane. The movements were made at angles of 0, 30, 60 and 90 degrees to the subject's right and the diameter of the target was 1/4, 1/2, 3/4 and 1 inch. Scores were based on the number of hits on the target within 20 second trials and hence were really a combination of accuracy and speed. He found that the angle at which most hits were made was 30 degrees for both inward and outward motions. The scores were consistently higher

for all angles with the target out rather than in. From a fitted curve, he concluded that the best angle for outward movements was 27 degrees and for inward movements was 37 degrees.

Raphael's (1955) research project included two studies, one done in the laboratory and the other in different industries. In the laboratory eight operators performed the task of moving 12 X 4 X 6.25 inch wooden boxes from the right with the right hand to in front of the operators and then move to the left with the left hand. The weights of the boxes were varied from 2 to 25 pounds and the distances moved from 6 to 24 inches. The task was performed on a table while standing. The industrial task was performed by 22 men and 4 women which included moving weights from 2 to 120 pounds while the distances were from 1 to 30 inches. Raphael made use of film at a speed of 2000 frames per minute to find the time for different arm movements. He made the following conclusions:

(1) An arm movement involving weight was made up of two components. These were a static component to bring the object under the control of the hand and arm muscles, and a dynamic component in which the object was actually transported by the arm from one location to another.

(2) The time of the arm movement was affected by the distance of the movement. The dynamic component showed increasing time as distance increased. The static component time, however, was independent of the distance of performance of the motion.

(3) The time of an arm movement was affected by the weight involved in its performance. Both the static and dynamic component showed increasing times as the weight transported increased. However, in general, the magnitude of this increase was not as large as that due to distance or control requirements.

(4) The times of arm movements involving weight performed against and with the force of gravity were not indicated to be different. The velocity and acceleration characteristics differed, but the times remained essentially the same.

(5) The direction of an arm movement involving weight with reference to the horizontal plane did not affect the time of the static component of the motion. It did affect the dynamic component. As the direction approached a vertical (90-degree) angle with the horizontal, the dynamic component time increased significantly.

(6) Arm movements involving weight performed by the preferred or nonpreferred hands did not show significantly different times.

(7) Male and female performance of arm movements involving weight were significantly different. The difference in static component times increased as weight moved increased, but was not affected by the distance of the motion. The actual movement time differences increased with increasing weight and increasing distance of performance. However, the percent or proportional movement time difference remained relatively constant regardless of weight moved or distance of performance.

(8) As the weight moved increased, the distance of performance of the arm movement tended to be reduced by industrial workers. There was some indication that operators tended to keep the amount of work performed in an arm movement within a restricted range.

(9) The static component time increased approximately .0000037 hours per pound of weight to be moved.

(10) The dynamic component time increased approximately 1.1% per pound of weight moved over the time with negligible weight.

Schmidtke (1958) conducted an experiment in Germany to investigate the influence of motion speed on motion accuracy. The subjects struck a target with a stylus by moving the hand at various speeds between the target point and the starting point. The task was performed by six subjects and the motion speed was varied between 10 and 100 cm./sec. The mean distance from the target point to the starting point was kept 40 cms. and the motion rhythm was controlled by a metronome. The error (the deviation from the target center) in millimeters was registered. The minimum errors were registered for the speed between 20 and 25 cm./sec. For the speeds less than 20 and greater than 25 cm./sec., there was an increasing tendency in the amount of errors.

Schmidtke and Stier (1961) studied the motion time as dependent on the direction of motions at an arbitrary velocity of movements. The task included a horizontal board with eight

round contact surfaces of 25 mm. diameter each at increments of 45°, arranged in a circle 40 cm. in diameter. The subject was asked to move forward and backward in any direction, always touching the contact surfaces with the stylus. They concluded that the shortest motion times were at 55 degrees and greatest ones at 145 degrees.

Wu (1965) investigated the effect of angle and work table height for ten right-handed subjects. The task was to move a two pound weight with the right hand from a central point to peripheral points 15 inches away at 0, 45, 90, 135 and 180 degrees and return to the central point. The three o'clock position was defined as zero. With the help of a metronome the speed was held constant. The physiological cost was measured by a force platform. Wu concluded that the movement was most efficient at 0 degrees and least efficient at 135 degrees. Outward movements involved less physiological cost than inward movements. Jeans (1966), in his study of two hand motions, did not agree with Wu and concluded that outward movements involved more physiological cost than inward movements.

Lincoln and Konz (1966) investigated the effects of speed and accuracy on operating switches and concluded that 45 degrees moves were better than 135 degree moves.

Konz (1967), from five different studies, concluded that the best height for a standing operator is one inch below the elbow although the working height can vary several inches up or

down without much effect on performance. For right handed movements, movementsto the right (that is, a forearm pivot about the elbow) are more desirable than movements to the left (that is, a movement of the entire arm from the shoulder).

Rathore (1968) investigated the effect of angle and distance on speed and accuracy. The task consisted of seven angles (0, 30, 60, 90, 120, 150 and 180 degrees) and two distances of movements (9 and 16 inches). The subject struck the target with a stylus by making repetitive hand movements between the inner and outer targets. Seven female subjects participated in the experiment. It was found that the angle of best response for the right hand was 60 degrees for both distances, while that for the left hand was 90 degrees at 9 inches and 120 degrees at 16 inches.

Bratton (1959) studied the cost to the body in standing to work and sitting to work in two experiments. The first task consisted of disassembly and assembly of a child's brightly colored toy and the second consisted of folding and stacking towels and work clothes. She measured oxygen consumption and concluded that there was no significant differences between the energy cost of sitting and standing. She also stated that her results confirmed that of Swartz (1933) in paring potatoes.

The literature survey revealed the following points:

1. There is no published data of any experiment investigating the effects of weights, angles and speeds on the physiological costs of sitting versus standing.

2. Different variables, namely speeds, weights and direction have been used separately by different investigators but no experiment is reported which compared all the three variables in the same task.
3. Barany (1963) studied the relationship between the anthropometric measurement (arm reach, chest circumference, height and weight) and the force exerted per unit of production. But his task did not include different angles, speeds, weights or position.

Taking into account the above points, it was decided to test the following hypotheses about the single hand (preferred hand) motions in the horizontal plane.

Hypotheses:

1) Moving weights between a center point and target points requires less physiological cost (output from the force platform) while standing than sitting.
2) Physiological work i.e., static and dynamic force, increases with increase in weights.
3) There is a best angle in the horizontal plane at which minimum amount of physiological cost is required which will be indicated by a statistically significant force-time value.
4) There is a relationship between the anthropometric measurement (arm reach, chest circumference, height and weight) and the total physiological cost.

METHOD

Task and Apparatus

(1) Adjustable work table (Plate 1 ,2)

A table 26 inches in depth and 52 inches wide was used for this project. The table top was covered by a white drawing sheet, on which the locations of the 2.5" diameter targets for each condition were marked clearly. Since Barnes (1940) had suggested that the place where the object being worked upon should be located 3 to 7" in front of the subject on the table the center of the 2.5" diameter central point was located 5 inches from the front edge of the table. From the center of the central target a semicircle 12 inches in radius was constructed.

The outer ends of the radii drawn at angles of 0, 45, 90, 135 and 180 degrees were marked as A,B,C,D and E respectively (zero degrees is referred to as three o'clock position). In the various experiments conducted in the past for finding the effects of direction on the movement of the hand (Schmidtke and Stier (1961), Wu (1965), Konz (1967)), these were the angles investigated. The table was placed on a hydraulic lift so that it could be adjusted to one inch below the elbow height of the subject as recommended by Konz (1967).

(2) Target assembly plate

Two identical targets (2.5 inches diameter x 1/16 inch thick) with their centers 12 inches apart were mounted on a

4 x 16 inch steel plate. The target assembly plate was fixed on the adjustable table in such a manner that it could rotate freely at the center of the central target.

(3) Weights (Plate 1,2)

The subjects worked with 1, 3 and 5 pound weights. The diameter of all the weights was 2 inches. Raphael (1955) concluded that the difference between male and female performance remains the same up through five pound weights, so 5 pounds was used as the maximum weight.

(4) Adjustable chair (Plate 2)

The chair seat and the back rest could be adjusted vertically and horizontally to regulate the working height of a subject.

(5) Metronome

A metronome was used to pace the subject's work motion. According to Schmidtke (1958), the speeds below 10 cm./second and above 100 cm./second cannot be considered continuous dynamic motions. The speeds of 30, 50 and 70 cm./second were selected to be in the range of continuous dynamic motions.

(6) Measuring tape

A measuring tape with 1/2 inch increments was used for taking the anthropometric measurements of the subject.

(7) Scale

The scale was used to take the subject's weight.

EXPLANATION of Plate 1

The layout of apparatus used to measure the force-time in the standing position.

EXPLANATION of Plate 2

The layout of the apparatus used to measure the force-time in the sitting position.

EXPLANATION of Plate 3

The top view of the force platform used in this study.

(8) Stop watch

A decimal-minute stop-watch was used to time the 15 second trials and the rest periods.

(9) Planimeter

A planimeter was used to determine the area of physiological cost from the record paper.

(10) Force platform (Plate 3)

The force platform used in this study was designed by Hearn (1966). The forces in the three perpendicular axes were recorded graphically on two two-channel oscillographic recorders. Only three of the four channels were used.

Subjects

Ten right-handed students were paid by the hour. Their ages varied from 21 to 27 years; their height from 64 to 73 inches and their elbow heights ranged from 39 to 44-1/2 inches. Table 1.

Statistical Design

Hypothesis one (sitting versus standing) was tested using a paired comparison t-test: (Snedecor, 1961). The null hypothesis might be stated:

$$Ho: \mu_d = 0$$

$$Ha: \mu_d \neq 0$$

$$t = \bar{d}/S_{\bar{d}}$$

$$d_{(i)} = S_{(i)sit} - S_{(i)stand}$$

Table 1

Personal data for subjects

Subject	Initials	Major	Age, Years	Weight, Pounds	Height, Inches	Fore Arm length, Inches	Upper Arm length, Inches	Elbow Height, Inches	Chest Circumference, Inches
1	L.D.	Ind.Engr.	21	146	68	14	13	43	34
2	S.S.	Ind.Engr.	21	160	72	14	14-1/2	44-1/2	36
3	S.A.	Ind.Engr.	26	151	70	13-1/2	14-1/4	43	35
4	S.P.	Ind.Engr.	21	154	72	14	14	44	33
5	W.N.	Ind.Engr.	25	136	67-1/2	13	14	43	33
6	S.S.	Ind.Engr.	23	128	64	13	13	39-1/2	31
7	F.M.	Math.	23	132	65	13	13	40-1/2	33
8	H.J.	Stat.	27	174	73	14	14	39	38
9	S.R.	Arch.	23	140	67-1/2	13	13	42	34
10	R.V.	Ind.Engr.	23	128	64	13	13-1/2	39-1/2	34

$$S_{\bar{d}}^2 = \frac{d_{(i)}^2 - \frac{(\Sigma d_{(i)})^2}{n}}{n(n-1)}$$

$\bar{d}$ = the average of $d_{(i)}$

$S_{(i)sit}$ = the physiological cost in the sitting position for the ith subject

$S_{(i)stand}$ = the physiological cost in the standing position for the ith subject.

n = the total number of observations.

The null hypothesis is rejected if $|t| \geq t_{n-1,.01}$ where $t_{n-1,.01}$ is the tabled student's statistic with (n-1) degree of freedom.

The experimental design for hypotheses two and three was a four factor, completely randomized, mixed factorial design as the main effect of subjects was random and the main effects of speeds, weights and angles were fixed. The following is the mathematical model and description of the terms,

$$\begin{aligned} Y_{ijkl} = \mu + S_i + Sp_j + W_k + A_l + SSp_{ij} + SW_{ik} + SA_{il} \\ + SpW_{jk} + SpA_{jl} + WA_{kl} + SSpW_{ijk} + SSpA_{ijl} \\ + SWA_{ikl} + SpWA_{jkl} + SSpWA_{ijkl} + e_{ijkl} \end{aligned}$$

where Y denotes the physiological cost.

μ denotes the true response of the over-all mean.

S denotes the effect due to subjects.

Sp denotes the effect due to speeds.

W denotes the effect due to weights.

A denotes the effect due to angles.

i denotes the number of levels of subjects.

j denotes the number of levels of speeds.

k denotes the number of lels of weights.

l denotes the number of levels of angles.

e denotes the effect due to experimental error.

Hypothesis four was tested using multiple linear regression analysis. The following is the mathematical model:

$$Y_i = a + b_i X_{1i} + b_2 X_{2i} + b_3 X_{3i} + b_4 X_{4i}$$

Where Y_i denotes total physiological cost by the ith subject.

X_{1i} denotes the weight of the ith subject.

X_{2i} denotes the height of the ith subject.

X_{3i} denotes the chest circumference of the ith subject.

X_{4i} denotes the arm-length of the ith subject.

a is a constant.

b_1, b_2, b_3, b_4 denote the slope of the regression line X_1, X_2, X_3 and X_4 respectively.

Experimental Procedure

Each subject was brought into the experimental room where the following anthropometric measurements were taken: (1) height (2) weight (3) chest circumference (4) fore arm length (5) upper arm length (6) elbow height.

The measurement of length of his upper arm was taken from the tip of the elbow to the top of the shoulder. While taking the above measurement, the subject was asked to keep his upper arm in a vertical position adjacent to his body with his fore arm at right angles to the upper arm. The elbow height was measured from the floor. After taking the elbow height, the height of the table was adjusted to a height one inch below the elbow. His personnel data such as name, age and major course of study were also recorded. Table 1.

Next, the subject was asked to go through the instruction sheet which was kept on the table. The instructions read as follows:

"This experiment has been designed to explore some of the relationships of the human to his work place and the tasks which he performs there. You will notice that the work place has been marked with a central point, X, and targets points A,B,C,D and E located on the semicircle with center X. Your part in this experiment will be to perform a series of moves with a weight in your right hand as directed from central point X to target points A,B,C,D and E. You will start your task by first touching the central point in front of you and then moving to touch the target and return to the starting position. Thus every time you touch the target. You will have to make one 'in' and one 'out' motion. When you are asked to perform the movement at a constant speed, you will be required to keep pace with the tone of metronome placed in front of you. The direction of the target speed and weight will vary from trial to trial. Try to place the weight fully within the target, but do not use excessive care doing so. In the first part of the experiment you will be sitting or standing depending upon the sequence. In the second part it will be the reverse. Before starting the actual experiment, you will be given practice trials, so as to enable you to become conversant with the task. You will be allowed 15 seconds for each trial and after a set of every ten trials you will be given a rest of 3 minutes.

You are now about to begin the task. Mount the platform without extreme movements. Stand naturally in case you are performing the task while standing with your feet touching the line drawn on the platform. If you are performing the task while sitting, climb the chair without excessive movements.

The experimenter will say "get set" and then "go".
As soon as you get the signal 'go', with your right hand grasp the weight. Lift your hand to hit the respective targets and return to the starting position for hitting the circular central point.
Repeat this operation with the beat of metronome until you get the signal 'stop'. Be careful not to shift your body to any new position after you begun to tap the targets.
Do you have any questions?"

Any questions by the subjects were answered immediately during the course of reading.

In order to minimize the effect of learning and fatigue on the performance of the task, a different sequence was used for each subject. The sequence of performing the task was randomized by using a set of random numbers. The sequence of trials for each subject under each condition and position is shown in Table 2.

Each subject performed a total of 45 trials while standing and 45 while seated. The cycle time for each trial was 15 seconds, and the rest period after completion of 10 trials was three minutes. Total duration for completion of the task by each subject was two and a half hours.

In order to make the subject conversant with the task, each subject was given a practice session of 20 trials. The practice trials with different combinations of angles, weights and speeds were presented in a random order. After completion of the practice trials, the subject was given a rest of three minutes.

Table 2

Experimental Sequence

Subject	Position First	Sitting (Y)	Standing (X)
1	X	Cb2 Bb4 Aa1 Cc3 Bc4	Cc4 Ab4 Aa4 Cc1 Ac5
		Bc2 Aa3 Ab4 Ba4 Cb5	Bb5 Cc5 Bc3 Ab1 Cc2
		Ac3 Bb3 Ca1 Ca5 Bb5	Ac1 Cb4 Ab5 Aa3 Bc4
		Cb3 Bc3 Ba1 Ac1 Cc1	Ab2 Cb1 Cb3 Bb3 Bb1
		Aa2 Cb1 Ab2 Ba5 Ca2	Ca1 Bb2 Ca2 Aa2 Ca4
		Cc2 Ac4 Ba3 Cb4 Ba2	Bc5 Ab3 Ba5 Ba2 Aa1
		Ca4 Ac2 Bb1 Bc5 Aa5	Ac3 Cb5 Bb4 Cb2 Ba3
		Bc1 Bb2 Ac5 Ca3 Cc5	Cc3 Ba4 Ac4 Aa5 Ca5
		Aa4 Ab1 Cc4 Ab3 Ab5	Bc2 Ba1 Ca3 Ac2 Bc1
2	Y	Ac1 Ab5 Bc5 Ba4 Aa1	Bc1 Bb3 BB4 Cc2 Aa5
		Ca3 Bc2 Cb1 Ac5 Aa2	Aa2 Ca2 Bc2 Bc5 Aa1
		Ca4 Ba5 Ab1 Ca5 Ba1	Ab2 Ac4 Ac3 Cb2 Cb5
		Ac3 Ca1 Ac2 Bc3 Aa5	Ba3 Cc1 Ba1 Cb4 Ba5
		Bb2 Aa4 Cc5 Ba3 Bb3	Cc3 Bb2 Ca3 Ab3 Bc3
		Bb4 Cb3 Ab2 Ac4 Ba2	Aa4 Bb1 Ab1 Cb3 Ab4
		Ab4 Bc1 Bb1 Cc1 Ca2	Ac5 Ac2 Cb1 Ba2 Cc5
		Bc4 Cb2 Cc3 Cc2 Cc4	Ca5 Ab5 Ca1 Aa3 Ac1
		Bb5 Ab3 Cb5 Cb4 Aa3	Ca4 Bb5 Cc4 Bc4 Ba4
3	X	Cb4 Bb5 Bc5 Bb2 Ca2	Ac3 Ba4 Ba5 Bb1 Ca4
		Ab5 Cb1 Cc5 Bb3 Ca3	Cc3 Bc2 Ba3 Aa3 Ca5
		Ba5 Aa1 Cc4 Ab1 Ba4	Aa4 Bb2 Ca3 Ac5 Aa5

Cont...

Table 2 Cont...

Subject	Position first	Sitting (Y)	Standing (X)
3	X	Ac4 Cb5 Cb2 Bb4 Ac3	Cb4 Cc5 Ba2 Bc5 Ca1
		Ac1 Bc4 Cc2 Aa5 Ba2	Aa1 Ca2 Cc1 Ac2 Ab3
		Cc1 Bc1 Ca1 Ca4 Ab4	Ab5 Bc1 Ab1 Bc3 Bc4
		Cb3 Bb1 Ba1 Ba3 Ab2	Cb2 Ba1 Cb1 Ac4 Aa2
		Ac5 Ca5 Ac2 Bc2 Aa2	Bb5 Cb3 Bb4 Ab2 Cc4
		Cc3 Aa3 Bc3 Ab3 Aa4	Bb3 Cc2 Ab4 Cb5 Ac1
4	Y	Bc3 Aa5 Ba3 Bb2 Ac1	Ac1 Cc2 Ab4 Bc3 Cb5
		Cb2 Cc5 Ba4 Bc1 Aa1	Bb2 Bc2 Cc4 Ca4 Aa3
		Ac5 Ba5 Cc2 Cb4 Bb5	Cb1 Ac3 Ba4 Ac4 Ca5
		Ab5 Ba1 Bb3 Aa2 Ab3	Bc4 Ac2 Bc5 Bb5 Ba1
		Ca4 Bc5 Bb4 Cc3 Bb1	Ba3 Bb1 Bb3 Ab1 Aa1
		Ab2 Cb1 Ca3 Aa4 Bc2	Ba5 Ca3 Aa5 Ac5 Cc5
		Cc4 Cb3 Ac3 Ca5 Aa3	Ab5 Cc1 Ba2 Ab2 Cb3
		Ac2 Bc4 Cb5 Ac4 Ba2	Cb4 Bc1 Ca1 Aa2 Cb2
		Ab4 Ca1 Ab1 Ca2 Cc1	Aa4 Ab3 Cc3 Bb4 Ca2
5	X	Cb5 Ba5 Bb1 Ba2 Ca1	Cc4 Aa1 Bb2 Ca3 Cc5
		Ab4 Ba1 Ca4 Bc1 Bb4	Ac1 Cb5 Ab4 Cb2 Ca5
		Ab1 Bb3 Cc2 Bc5 Cc5	Bc1 Cb4 Aa4 Ba5 Ab5
		Aa4 Ac3 Cb1 Ca5 Cc1	Ba2 Ab3 Aa3 Aa5 Bb1
		Cb2 Ac5 Ab2 Cc3 Ca3	Ba1 Aa2 Ca1 Bb1 Cb1
		Ba3 Bc2 Ba4 Ac2 Aa1	Cc3 Bc3 Bb4 Ac3 Ca2
		Bb2 Aa2 Aa5 Bc4 Ca2	Ba3 Cb3 Ab2 Bc4 Bc5
		Bb5 Ab5 Ac1 Cb4 Aa3	Ca4 Cc2 Ac4 Ac2 Ba4
		Cc4 Ab3 Cb3 Ac4 Bc3	Bc2 Bb5 Cc1 Ab1 Ac5

Cont...

Table 2 Cont...

Subject	Position First	Sitting (Y)	Standing(X)
6	Y	Bb3 Bc3 Aa5 Cb5 Cb2	Ca3 Bc4 Ac4 Ba3 Ac2
		Bb1 Ac5 Aa2 Cc1 Bb2	Ca4 Ac3 Ab2 Cb3 Ab4
		Aa4 Ab1 Ca1 Cc5 Bc5	Bb3 Bc1 Aa5 Ab1 Ba2
		Ba5 Ac4 Cb1 Bb5 Aa1	Ca1 Aa3 Cb2 Bc5 Cb1
		Bc4 Ba1 Ba2 Bc2 Cc4	Bb2 Ac5 Cb4 Ab5 Ca5
		Ab2 Cc1 Cb4 Ba3 Ac3	Cc5 Cc1 Ba4 Ca2 Bb5
		Ca5 Aa3 Ca2 Ba4 Bb4	Bc2 Aa1 Ab3 Cb5 Bb1
		Cc3 Cb3 Ac2 Ab4 Ca4	Aa4 Aa2 Ba1 Ac1 Cc4
		Ab5 Bc1 Ca3 Ab3 Ac1	Ba5 Nc3 Cc3 Bb4 Cc2
7	X	Ca5 Ac4 Aa5 Ba3 Ab3	Bb1 Bc2 Aa3 Ac2 Ba5
		Ac1 Cb2 Cb5 Aa3 Bc1	Ab5 Ab1 Cb4 Bc1 Bb5
		Ba5 Bb3 Cb1 Ba4 Cc5	Bc4 Aa5 Ac5 Ca3 Cc3
		Ca1 Cc4 Ac2 Ca2 Ba2	Cb3 Ab2 Bb2 Ca4 Ca5
		Ca4 Bb2 Ba1 Cb3 Cc2	Ac1 Aa1 Bb4 Cb2 Bc5
		Aa4 Bb1 Ac3 Bc3 Cb4	Ab3 Ba4 Cc5 Ba2 Cb5
		Ab2 Ab4 Cc1 Bb4 Aa2	Bb3 Ac3 Ac4 Ba1 Cc2
		Ac5 Bc5 Aa1 Bc2 Ca3	Ca1 Cc4 Ab4 Aa4 Bc3
		Ab5 Bb5 Ab1 Cc3 Bc4	Ca2 Cb1 Cc1 Aa2 Ba3
8	Y	Ba5 Bb2 Cc5 Cc4 Ba1	Ab5 Bb3 Ca2 Bc5 Ac4
		Aa4 Ca2 Aa3 Aa1 Bc2	Bb1 Ca5 Ca3 Ba4 Ca1
		Ac1 Ab3 Cb2 Aa5 Cb5	Bb4 Cb3 Cc5 Ba1 Cc2
		Ca3 Ba4 Ba3 Ab2 Ba2	Bc1 Cb4 Aa3 Aa4 Ab2

Cont...

Table 2 Cont...

Subject	Position First	Sitting (Y)	Standing (X)
8	Y	Aa5 Bc4 Bb3 Ac3 Bc1	Bb2 Bb5 Ac1 Ba3 Cc1
		Ab5 Cc3 Cc2 Ac2 Ca1	Cc4 Aa5 Cb5 Ab4 Bc4
		Bc3 Aa2 Bb5 Ab5 Bc5	Bc3 Ac2 Aa1 Ac3 Ca4
		Cb1 Ca4 Ab1 Ac4 Cb5	Aa2 Ac5 Ab1 Bc2 Ba5
		Bb4 Ca5 Cb3 Cb4 Bb1	Ab3 Cc3 Cb1 Ba2 Cb2
9	X	Ab3 Ac4 Bb4 Aa1 Bc5	Ac4 Aa2 Ba4 Ca1 Bc3
		Ca2 Ca3 Ba4 Bc3 Cb5	Ac5 Aa1 Ab4 Cc3 Bb2
		Aa2 Bb1 Ca4 Ac3 Cc1	Bb1 Ba2 Cc1 Cb2 Ba1
		Aa3 Ac2 Ac5 Ba2 Bc1	Ab1 Aa4 Cb4 Ab5 Aa5
		Aa4 Bb5 Ba5 Cb4 Ca1	Ca4 Bb3 Ac3 Ab3 Bc1
		Bb3 Bc2 Cc4 Cc5 Cb2	Ab2 Ac2 Aa3 Ba3 Ca3
		Ac1 Bc4 Ba1 Cc2 Aa5	Bc2 Ca2 Cc4 Bb5 Ca5
		Ab4 Ca5 Ab2 Bb2 Ab1	Bc4 Cc2 Ac1 Cb1 Bc5
		Cb3 Ba3 Cb1 Cc3 Ab5	Bb4 Cc5 Ba5 Cb3 Cb5
10	Y	Cb4 Ca3 Cc2 Ab1 Bc2	Ca2 Bc4 Bc2 Ac4 Cc1
		Bc1 Bb3 Ac1 Ca1 Bc3	Bc3 Ba5 Ba4 Bc1 Ac5
		Cb2 Bc4 Ca4 Bb2 Ab2	Aa3 Cb5 Aa5 Ba1 Bb5
		Bb4 Bb1 Ac4 Ab5 Bc5	Ac3 Ca3 Ac1 Cc5 Aa2
		Ba2 Cc1 Ab3 Ba4 Ca5	Bc5 Bb3 Ac2 Ca5 Cb2
		Aa4 Cc4 Aa1 Aa5 Cc5	Ba2 Cc4 Cc2 Bb2 Cb4
		Aa3 Aa2 Cb5 Ca2 Ac2	Ba3 Cb1 Ab3 Bb1 Ab4
		Ba1 Ba5 Cb3 Ac5 Cc3	Cc3 Aa4 Ca1 Ab1 Ab2
		Ba3 Ac3 Bb5 Cb1 Ab4	Aa1 Cb3 Ab5 Ca4 Bb4

Where:

A - 30 cm./second	a - 1 pound weight	1 - 0°
B - 50 cm./second	b - 3 pound weight	2 - 45°
C - 70 cm./second	c - 5 pound weight	3 - 90°
		4 - 135°
		5 - 180°

When the subject began the experimental task, the experimenter assumed a position near the subject to verbally indicate to him the sequence and also the beginning and end of each work cycle by the words "go" and "stop". One other experimenter assumed a position in front of the recorders to adjust the recording pens to a null position after every ten trials and to push buttons provided on the recorders to mark the start and end of each movement while it recorded data on the X (lateral), Y (frontal) and Z (vertical) axes. By calibration with known weights, it was found that one square inch of area on the output paper was equal to 17.20 pound-seconds in the X, 25.80 in the Y and 32.25 in the Z plane.

The experimenter converted the area under the curve into pound-seconds by multiplying by the corresponding constants. The pound-seconds for all the three axes X, Y,and Z were added arithmetically to determine the physiological cost.

RESULTS

To test the first hypothesis that moving weights between a center point and target points requires less force-time while standing than sitting, a paired comparison t-test was applied

to the standing and sitting data. Table 3. Since the t-test value obtained was greater than the critical tabled value at the one percent level, standing requires less energy than sitting in the performance of the task. Force-time in the sitting position (average force-time value per subject equalled 4400 pound-seconds) was 1.46 times greater than force-time in standing (3000 pound-seconds), which is also apparent from Figure 1. There seems to be a linear relationship between sitting and standing force-time value with increase in weights moved (Figure 2).

An analysis of variance applied to the complete data of the standing position showed that the main effects of subject, weight, angle and the first order interaction of weight x angle were significant ($p<.01$). Table 4. In the sitting position, all the main effects of subject, speed, weight, angle and the first order interactions of subject x speed, subject x weight, subject x angle, speed x weight, speed x angle, weight x angle and the second order interaction subject x weight x angle were significant ($p<.01$). Table 4.

Duncan's New Multiple Range Test ($p<.05$) was employed to determine the significant statistical differences among the different means in a variable. Mean response scores of weight, angle, speed (Table 5) and of their interaction (Table 6) for both the positions were used.

Table 3

The difference between sitting and standing position work. ($d_{(i)} = S_{(i)sit} - S_{(i)stand}$), $i = 1$ to 10

Subjects	$d_{(i)}$
1	1328.42
2	1257.91
3	1358.06
4	1139.12
5	1433.78
6	728.78
7	1781.37
8	2284.67
9	1901.93
10	780.23

$\overline{d} = 1399.43$ $S_{\overline{d}} = 153.10$ $t = 9.14^{**}$

$^{**}p<.01$

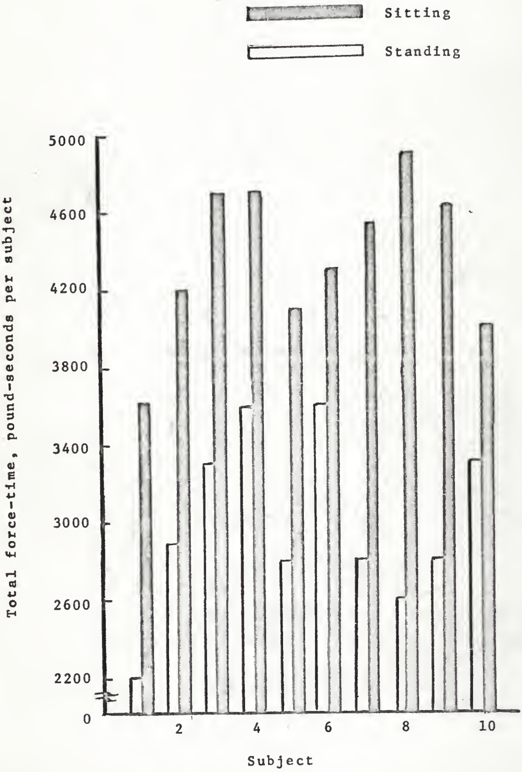

Figure 1. Comparison between sitting and standing.

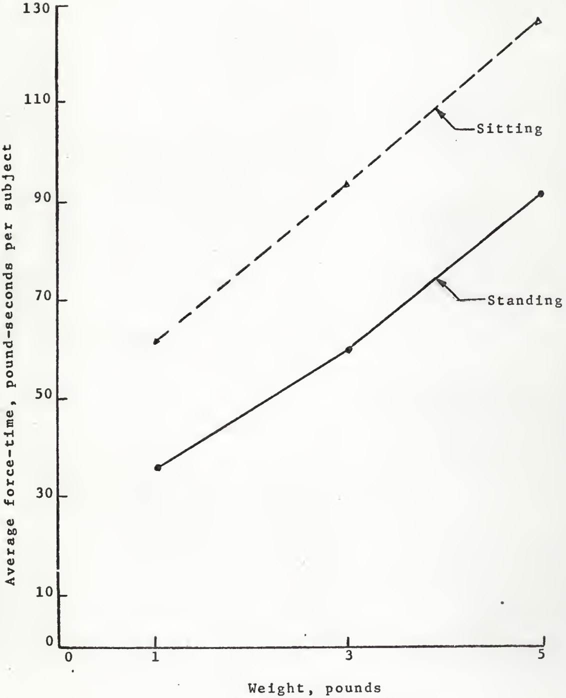

Figure 2. Effect of weight on force-time.

Table 4

Analysis of variance of physiological cost in the standing and sitting positions.

Source	d.f.	Standing M.S.	Standing F	Sitting M.S.	Sitting F
Subjects (S)	9	3779.34	419.92**	3356.10	372.90**
Speed (Sp)	2	593.21	1.67	42562.49	75.83**
Weights (W)	2	71139.98	254.18**	106763.54	277.64**
Angles (A)	4	9111.63	31.41**	16637.97	16.59**
S X Sp	18	354.70	2.06	561.24	3.21**
S X W	18	279.87	1.64	384.53	2.20**
S X A	36	290.08	1.70	1000.71	5.74**
Sp X W	4	317.44	1.74	1421.05	6.30**
Sp X A	8	274.57	1.24	963.53	4.20**
W X A	8	15128.89	91.08**	10410.58	20.82**
S X Sp X W	36	182.37	1.07	225.43	1.29
S X Sp X A	72	220.66	1.29	229.39	1.29
S X W X A	72	166.09	0.97	449.94	2.86 **
F X W A	16	302.07	1.77	324.97	1.86
S X Sp X W X A (Error)	144	170.31	-	174.47	-
Total	449				

** p<.01

From Table 5 and Figure 3, it can be seen that as the speed increased, there was a corresponding increase in the force-time value in the sitting position but it was relatively constant in the standing position. The F-ratio was significant for sitting but not for standing. There was significant difference in the sitting position between 30 and 70 cm./second but 30 and 50, and 50 and 70 cm./second were not significantly different from each other.

The second hypothesis was tested by finding the weight effect on force-time. The weight effect was significant in both sitting and standing position ($p<.01$). Weights of 1, 3 and 5 pounds were significantly different ($p<.05$) from each other in both positions. Table 5. The increase in force-time with increase in weight can be seen in Figure 2. The maximum amount of force-time was 90.99 pound-seconds in standing and 126.37 pound-second in sitting position with a 5 pound weight. The minimum amount of force-time with a 1 pound weight was 35.51 pound-seconds in standing and 61.38 pound-seconds in the sitting position. Table 5. On an average, 0.73 pound-seconds of force-time were spent per pound weight per second in standing and 0.86 pound-second per pound weight per second in sitting position.

The third hypothesis (the angle in the horizontal plane at which minimum force-time is required) was found by applying Duncan's New Multiple Range Test ($p<.05$). Table 5. In the sitting position angles 0, 45 and 90 degrees were significantly

Table 5

Mean scores for speeds, weights, and angles. Those scores underlined by the same line are not significantly ($p<.05$) different.

Position	Speed, cms./sec.			Weight, pounds			Angles				
Sitting	70	50	30	5.0	3.0	1.0	180°	135°	90°	45°	0°
	113.52	95.24	79.88	126.37	92.54	61.38	114.75	107.35	90.44	80.57	74.03
							135°	180°	90°	45°	0°
Standing				90.99	59.64	35.51	77.12	75.50	58.63	54.31	44.68

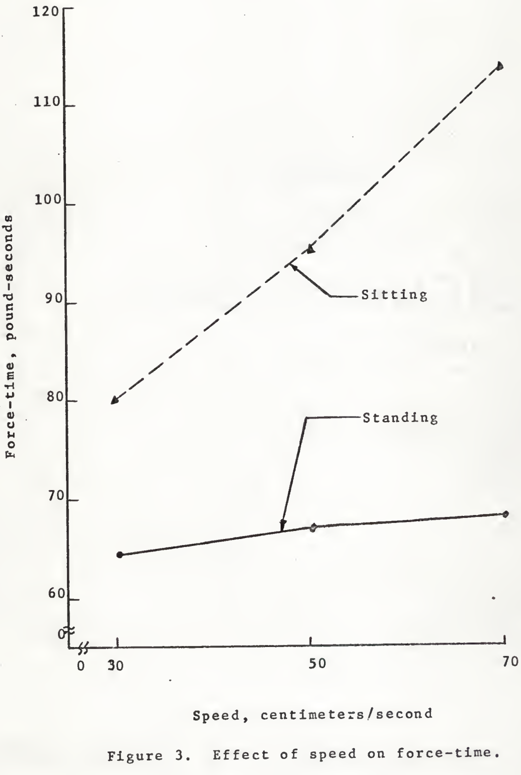

Figure 3. Effect of speed on force-time.

different from each other. Minimum force-time value was required at 0 degrees and maximum at 135 degrees (Figure 4). In the sitting position, 0 degrees was significantly different from 135 and 180 degrees and 45 degrees was significantly different from 180 degrees, but all other values were not significantly ($p<.05$) different from each other. In the sitting position, 0 degrees required the minimum force-time value but 180 degrees required the maximum (Figure 4). Therefore 0 degrees is the best and 135 and 180 degrees are the worst angles for the task performance.

Duncan's New Multiple Range Test ($p<.05$) was employed to determine the significant statistical differences among the means for the different interactions (Fryer (1966), page 350). From Table 6 and Figure 5 and 6, at the 1 pound weight there was no statistical difference ($p<.05$) between all the angles in both the positions. From the various significant tests, it can be concluded that, for all the weights, 0 degrees angle was best and 135 and 180 degrees angle was worst. For all the angles, 1 pound weight was best and 5 pound weight was worst.

The interaction between speed and weight was significant in the sitting position. Table 4. There was no significant difference between the 1 and 3 pound weight at 30 cm./second, but all other values were significantly ($p<.05$) different from each other. Table 6. An increase in weight increased the force-time value (Figure 7) at all the speeds. The minimum force-time

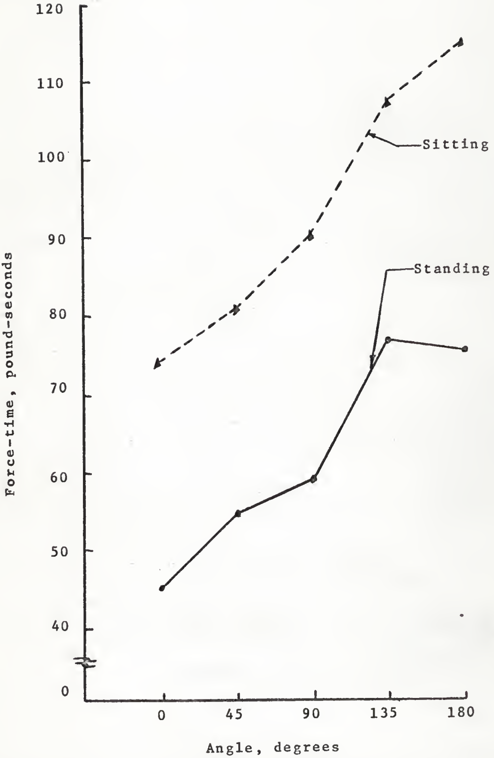

Figure 4. Effect of angle on force-time.

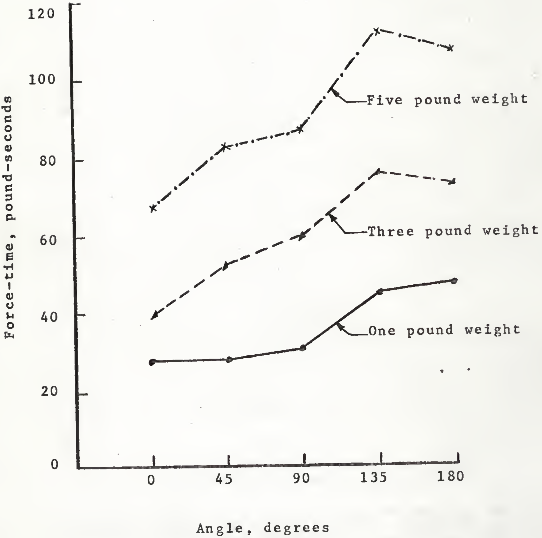

Figure 5. Angle x weight interaction in standing position.

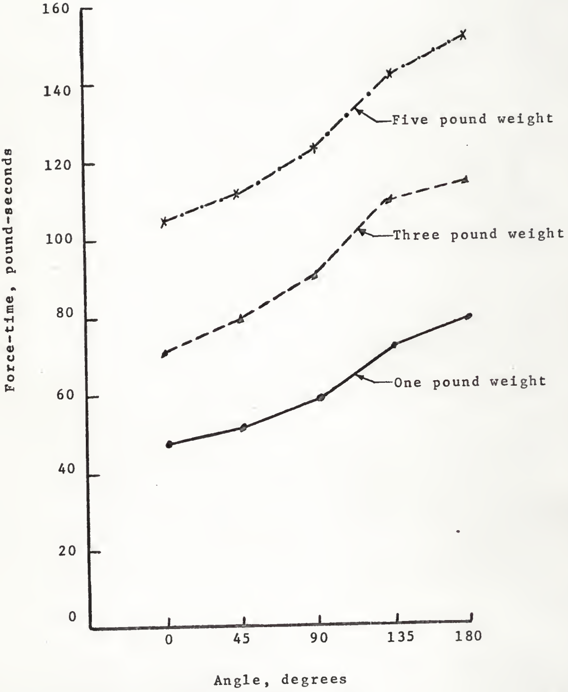

Figure 6. Angle x weight interaction in sitting position.

Table 6

Mean score for speed x weight, speed x angle, weight x angle. Those scores underlined by the same line are not significantly ($p<.05$) different.

Position	Variable	Weight, pounds			Angle, degrees				
Sitting	Speed, cm./sec.	1	3	5	0	45	90	135	180
	30	60.27	74.03	105.32	51.05	63.50	71.93	91.05	91.25
	50	65.90	91.88	127.93	81.07	82.00	91.62	104.56	115.91
	70	86.99	111.71	145.86	90.05	96.21	107.77	126.44	137.08
Sitting	Weight, pounds								
	1				47.21	51.04	58.32	71.44	78.88
	3				70.60	79.00	90.07	108.74	114.29
	5				104.30	111.67	122.93	141.87	151.08
Standing	1				27.80	27.80	30.06	44.17	47.74
					0	45	90	180	135
	3				39.42	52.24	39.35	72.16	75.05
	5				66.84	82.90	86.47	106.61	112.31

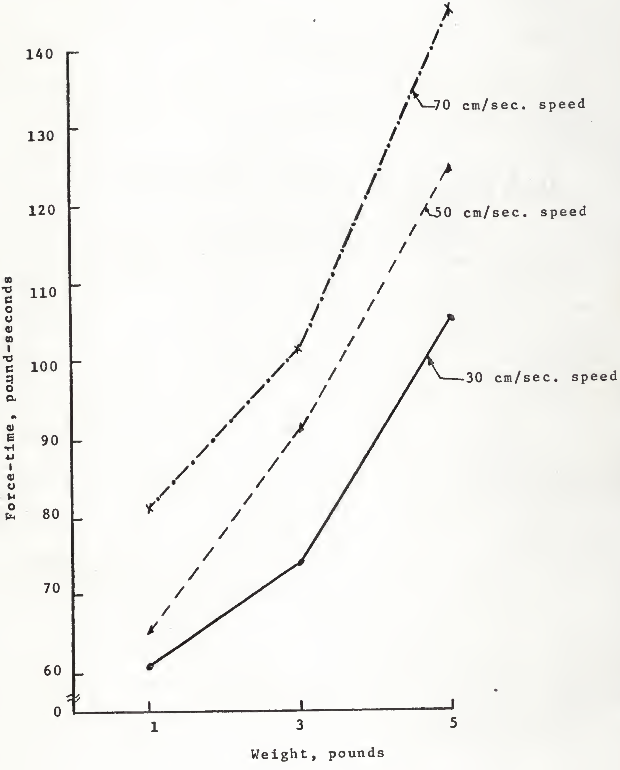

Figure 7. Weight x speed interaction in sitting position.

value was at 1 pound weight and 30 cm./second and the maximum force-time value was at 5 pound weight and 70 cm./second.

The efficiency was calculated at each of the weights and speeds (Table 7) from the following formula:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Physiological Cost}}$$

where, Output = Number of movements/trial x distance moved x weight

Physiological Cost = Output of force platform + arm weight x trial period.

Weight of arm was assumed to be 5.18% of the body weight (Contini, Drillis, and Bluestin, 1963). For the 30 cm./second speed with the one pound weight, the efficiency is:

$$= \frac{60 \text{ strokes/minute} \times 1 \text{ ft.} \times 1/4 \text{ minute} \times 1 \text{ lb.}}{60.27 \text{ pound-second} + 7.5 \text{ lb.} \times 1/4 \text{ minute}} = 8.1\%$$

The lowest efficiency was at 30 cm./second and 1 pound weight (8.1% for sitting and 9.4% for standing); the highest efficiency was at a speed of 70 cm./second and a 5 pound weight (65.2% for sitting and 86.5% for standing).

In the speed and angle interaction, there was no significant difference between 0, 45, and 90 degrees and between 90, 135 and 180 degrees ($p<.05$) but 0 and 45 degrees were significantly different from 135 and 180 degrees at 30 cm./second (Figure 8). Table 6. At 50 cm./second only 0 and 45 degrees were significantly different from 180 degrees but all other

Table 7

Mean efficiency at each combination of speed and weight.

Weight pounds	Sitting			Standing		
	speed, cm/second			speed, cm/second		
	30	50	70	30	50	70
1	8.1%	14.2%	17.1%	9.3%	15.7%	21.1%
3	24.2%	36.4%	46.1%	26.5%	43.3%	60.4%
5	36.9%	51.2%	67.1%	37.4%	60.5%	86.4%

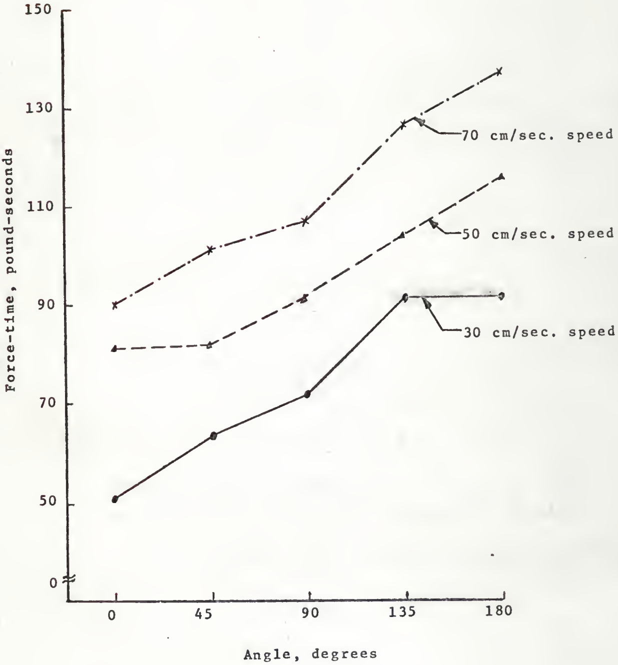

Figure 8. Angle x speed interaction in sitting position.

values were not significantly different from each other. At 70 cm./second, 0 and 45 degrees were significantly different from 135 and 180 degrees and 90 degrees was significantly different from 180 degrees. It was concluded (Figure 8) that for all the speeds, 0 and 45 degrees angles were best and 135 and 180 degrees angles were worst. For all the angles, 30 was best and 70 cm./second was worst from the standpoint of physiological cost, although 70 cm./second is best on a productivity basis.

The significant subject and weight, subject and speed, and subject and angle interactions were due to the highly significant subject effect. All this means that weight, angle and speed on the average were best at the values concluded earlier but some subjects had their minimum force-time values at some other weight, angle or speed.

Hypothesis four was tested using multiple linear regression analysis. The multiple linear correlation coefficient (R = .11) obtained by combining the four anthropometric measurements was not significant ($p<.05$). Therefore, hypothesis four was rejected. Table 8.

DISCUSSION

The results of the present experiment showed that there is a significant difference in the force-time value while performing the task while sitting versus while standing.

Table 8

Anthropometric Data and Measures of work

Subject	X_1 Weight, pounds	X_2 Height, inches	X_3 Chest Circumference, inches	X_4 Arm-length, inches	Y Force Time, pound-sec. (sitting and standing)
1	146	68	34	27	5829
2	160	72	36	28-1/2	7236
3	151	70	35	28	8033
4	154	72	33	28	8299
5	136	67-1/2	33	27	6848
6	128	64	31	26	7949
7	132	65	33	26	7415
8	174	73	38	28	7575
9	140	67-1/2	34	26	7418
10	128	64	34	26-1/2	7405

$R^2_{1.2345} = .012$

$R = .11$

$$F(p,n-p-1) = \frac{R^2_{1.2345}}{1-R^2_{1.2345}} \times \frac{(n-p-1)}{p}$$

$$= .015$$

Critical value : F = 4.90 at 5 percent level

n is the total number of observation.

p is the number of levels of anthropometric measurement.

The results contradict the results of Bratton (1959) and Swartz (1933). They concluded that there was no significant difference in the amount of energy spent in sitting versus standing position. The difference might be explained by the fact that their task was light and the measuring device used (oxygen consumption method) is not suitable for light tasks (Ingenohl, 1959). Ingenohl states that the dimension for weights to be chosen must reflect the transition points between weights which do or do not cause sustained body fatigue.

The reason for so highly significant a difference can be that the movements of the subjects were restricted in the sitting position, so it was not possible for the subject to make the necessary postural adjustments in order to compensate for the relative changes in the stress produced in the various muscles of the arm involved.

Furthermore, since each subject completed only 45 cycles of the task under each position, it would be difficult to extend the results of this investigation to the long run case. That is, if it had been practical to submit the subject to eight hours of task performance, one cannot say which position, if either, would have demanded less force-time. It should be noted that only the effect of movement was considered and not the cost of holding up the body.

Effect of Subject

The subject effect was highly significant in both the sitting and standing position ($p<.01$). Although subject effect was not one of the hypothesis of this investigation, it was expected that a specific subject's performance would vary from other subjects when doing the same task i.e., subjects do not perform alike.

Effect of Speed

Speed had a significant effect on the force-time in the sitting position. The non-significant effect of the speed in the standing position is very difficult to explain. An increase in speed increasing the force-time was the findings of previous investigators. For example, Schmidtke (1958) stated that for faster motions with constant mass and constant frictional resistance, there is larger force expense necessary than for slow motions.

Ayoub (1966) showed that the ventilation rate/body surface area (i.e., energy spent for the subjects) on the average increased 9.8 percent with an increase in pace from 80 to 100 percent and increased 14.5 percent with an increase in pace from 80 to 110 percent.

Effect of Weight

The significance of the weight in the sitting and standing positions can be explained by the definition of work in physics by taking into consideration the dynamic force only (the force

platform measures physiological work which is the total energy a man spends in doing work i.e., static and dynamic force). Work is defined as the product of force and the distance of action. If we take into consideration only the static force which increases with the increase in weight (Raphael, 1955), then for a given distance, the energy needed to do the work of moving a weight will increase as the amount of weight increases. However the combined static and dynamic force increases the energy spent (force-time) at a much higher rate than the increase in weight; this higher rate is apparent from Figure 2 and Table 5 and is in agreement with the results of Barta (1962). Barta concluded that the three components of external force increases at a much greater rate than the increase in time as the weight handled increased from 0.35 to 12.92 pounds. The increase in efficiency with increasing weight (Table 7) can be explained by the fact that the total weight moved includes the weight of the arm and the actual weight moved and, as the useful weight (actual weight moved) increases, the output of the subject increases at a higher rate than the physiological cost. For example, a 1 pound load requires the movement of a 7.5 pound arm so the "payload" is only 12% while a 5 pound load with 7.5 pound arm is a 40% "payload".

Effect of Angle

The results showed that the direction of path of movement has a significant effect on force-time value. A number of

workers in this area (Corrigan et. el. (1948), Briggs (1955), Wu (1965), Jeans (1966), Rathore (1968)) have obtained evidence that simple hand-arm movements are affected by the angles at which the hands are moving.

The reason for this effect may be that the movement of hands at different angles requires the functioning of different muscles and different number of joints starting from wrist joint to shoulder joint. The directions which involve the movement of least complexity may thus have minimum force-time value.

In this study, the subjects were not allowed to change the posture of the body while performing the task. Thus, whenever the angle of movement was changed, it was not possible for the subjects to make the necessary postural adjustments in order to compensate for the relative changes in the stress produced in the various muscles of the arm involved in the movements.

Starting from 0 degrees, the force-time increased to a maximum at 180 degrees for sitting position and to 135 degrees for standing position (Figure 4). The force-time value was minimum at 0 degrees for both the positions. This confirms the results of Wu (1965). Wu concluded that work in the inward direction increases rapidly as the angle changes from 0 degrees to 135 degrees for any specific work level but decreases for 180 degrees. On an average, the value of force-time increases .24 pound-second per degree with increase in angle from 0 to 135 degrees in the standing position and .22 pound-second per

degree with increase in angle from 0 to 180 degrees in the sitting position (Figure 4). This shows that there is a linear relationship between the two positions up to 135 degrees.

For the standing position there was no significant difference between 0, 45 and 90 degrees and between 135 and 180 degrees, but there was a significant difference between 0, 45 and 90 and 135 and 180 degrees in the standing position. This conforms with the results in the experiment five of Konz (1967). Konz concluded that the effect at 45 degrees and 90 degrees is not significantly different but 135 degrees is significantly worse than both 90 degrees and 45 degrees. He further stated that moving the right hand at 135 degrees is not only less effective, it is disliked by the subject, which again confirmed the results of both sitting and standing positions.

Interactions

The significant weight and angle interaction for both sitting and standing positions could be explained as follows. The force-time value increased at a much higher rate than the increase in weight; and the directions which involve the movement of most complexity had the maximum force-time value. Hence, 5 pound weight and 135 degrees or 180 degrees angles required the maximum force-time value as compared to 3 pound and 1 pound weights and 0 to 90 degrees angles (Figures 5, 6) Table 6. For all the weights, 0 degrees angle was best and 135 and 180 degrees angle were worst. For all the angles, the one pound weight was best and the five pound weight was worst.

Since force-time value was relatively constant with increase in speed in the standing position, the results showed no significant interaction between speed and weight or angle.

However, speed was highly significant in the sitting position and so was the interaction between speed and weight and speed and angle. It can be explained by the fact that the movements of hands at different speeds requires the functioning of different muscles and different number of joints. As the speed is increased, it causes an increase in the movements of the muscles and, if the weight is heavy or the direction involves greatest complexity, there is a tendency to hinder the fast movements of the hand. To overcome this, the subject had to exert more force-time.

The results from Table 6 and Figure 7 showed that minimum force-time was required at the lowest speed and smallest weight (30 cm./second and 1 pound weight) and the maximum force-time required was at the maximum speed and the largest weight (70 cm./second and 5 pound weight).

For the angles, as shown in Table 6 and Figure 8, the minimum amount of force-time for all the speeds was at 0 degrees angle and maximum at 180 degrees angle. Thirty centimeters per second and 0 degrees angle required the least force-time and 70 cm./second and 180 degrees angle required the maximum force-time, although 70 cm./second is best from productivity basis.

The significant difference of subject and weight, subject and speed, subject and angle, subject and weight and angle means

that although 1 pound weight, 30 cm/second speed and 0 degrees angle had the lowest force-time value on the average, some individuals had their lowest values at other weights, angles, speeds, weights and angles. Thus, although for this task using 1 pound weight, 0 degrees angle and 30 cm/second speed would require the least force-time value on the average, the optimum for a specific individual could only be determined by recording his output at all these conditions and then selecting his optimum condition.

Relation between Force-time and Anthropometric Measurement

It was found that there is no relationship between the anthropometric measurement and the force-time values ($p<.05$). Therefore, the results from the force platform do not appear to be appreciably affected by the physical size of the subjects.

The inability to predict performance from anthropometric measurements was in agreement with the finding of previous investigators. For example Barany (1963) found that within a group of thirty young men there was no relationship between the anthropometric measurement and the bodily forces exerted and the number of units produced. Barany also stated that Tiffin (1952) concluded that, in general, no appreciable relationship exists between the psychomotor abilities and anthropometric measurements except in extreme cases where a particular subject may have a physical handicap.

CONCLUSIONS

From the results of this experiment, and tasks studied, (1) Standing requires less force-time than sitting. Note that the effort to support the body is not considered. (2) There is an increase in force-time with increase in weights. (3) The angle for least force-time is zero degrees for all the weights, speeds and positions. (4) There is no relationship between anthropometric measurements (arm reach, chest circumference, height and weight) and the force-time value.

Finally, as has been pointed out, there may be other variables affecting the effort levels which were not accounted for in this investigation. It is believed that further experiments, designed to investigate the effect of such variables as length of performance and more replications, would extend the results of this investigation to provide a more adequate understanding of the effect of positions and of the second and third order interactions between weights, speeds and angles.

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THE PHYSIOLOGICAL COSTS OF ARM MOTIONS WHILE SITTING AND STANDING

by

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ABSTRACT

The study investigated the effect of weight and direction on the physiological costs of work performance in sitting versus standing positions through the use of a force platform.

Ten right-handed male subjects moved 1, 3 and 5 pound weights at 30, 50 and 70 cm./second from a central target to points 12 inches away at 0, 45, 90, 135 and 180 degrees.

It was concluded, for the task conditions of this experiment, that:

1. Standing requires less force-time than sitting. Note that the effort to support the body was not considered.
2. Force-time increases at a much higher rate than an increase in weight.
3. The angle for least force-time is zero degrees for all the weights, speeds and positions.
4. There is no relationship between anthropometric measurements (arm reach, chest circumference, height and weight) and the force-time value. Therefore, the results from the force platform do not appear to be affected by the physical size of the subjects.